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Technical Memorandum FM 41
GARTEUR TP 057

February 1990

**Final Report of
Garteur Action Group FM (AG)
03**

**"Integration of Flight Management
and
Air Traffic Management Systems"**

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ROYAL AEROSPACE ESTABLISHMENT

Technical Memorandum FM41

GARTEUR TP 057

FINAL REPORT

OF

GARTEUR ACTION GROUP FM(AG)03

"Integration of Flight Management

and

Air Traffic Management Systems"

SUMMARY

GARTEUR Action Group FM (AG)03 was set up in late 1984 to consider how airborne Flight Management Systems and the equivalent ground based Air Traffic Management System could work together to form a genuine Integrated ATM System. A particular problem was how best to utilise the airborne precision 4 dimensional navigation capability that was moving from the experimental realm to airline adoption. The resulting concept of a computer based strategic ATM system utilising 4D trajectories with defined tolerances has become known as the GARTEUR 4D Tubes in Space Concept. These concepts were developed through a series of publications and have proved to be very influential in shaping the thinking of groups such as the ICAO FANS Committee and the PHARE European experimental ATM programme. This final report describes the Group's activities and concludes with recommendations for the work of a successor group.

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GARTEUR ACTION GROUP
FM(AG)03
FINAL REPORT

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ABBREVIATIONS

A. ORGANISATIONS

BFS Bundesanstalt für Flugsicherung (FRG).
CAA Civil Aviation Authority (UK)
CEV Centre d'Essais en Vol (France).
DGAC Director General d'Aviation Civile (France).
DLR Deutsche Forschungsanstalt für Luft- und Raumfahrt (FRG).
ENAC Ecole Nationale de l'Aviation Civile (France).
ESA European Space Agency
FAA Federal Aviation Authority (USA).
GARTEUR Group for Aeronautical Research and Technology in Europe.
ICAO International Civil Aviation Organisation.
NLR Nationaal Lucht- en Ruimtevaartlaboratorium (Netherlands).
RAE Royal Aerospace Establishment (UK).
RSRE Royal Signals and Radar Establishment (UK).
SMFA Service du Matériel de la Formation Aeronautique (France).
STNA Service Technique de la Navigation Aérienne (France).

B. TECHNICAL TERMS

ACAS Airborne Collision Avoidance Systems (ICAO)
ACG Advanced Concepts Group (Eurocontrol)
ADS Automatic Dependent Surveillance (ICAO)
AEC Airborne Experimental Cockpit (DLR)
AERA Advanced En-Route Automation (FAA)
AI Artificial Intelligence
ART Avionics Research Testbed (NLR)
ATC Air Traffic Control
ATM Air Traffic Management
ATMOS Air Traffic Movement Simulator (DLR)
ATS Air Traffic Services
ATTAS Advanced Technologies Testing Aircraft System (DLR)
CNS Communication, Navigation and Surveillance (ICAO)
COMPAS Computer Oriented Metering Planning and Advisory System (DLR)
CMTF Common Medium Term Plan (Eurocontrol)
EFIS Electronic Flight Information System
EFMS Experimental Flight Management System (Eurocontrol)
FANS Future Air Navigation System (ICAO)
FEATS Future European ATS System Concept Group (ICAO)
FMS Flight Management System
GMS Ground Movement Simulator (DLR)
GPS Global Positioning System (ICAO)
GTIS Ground-based Traffic Information System (ICAO)
IRP Integrated Research Programme (UK)
MLS Microwave Landing System (ICAO)
NARSIM NLR ATM Research Simulator (NLR)
NASPLAN National Air Space Plan (FAA)
PHARE Programme of Harmonised ATM Research in the Eurocontrol Organisation (Eurocontrol)
PRODAT PROSAT for Aeronautical Data (ESA)
PROSAT Promotion of Satellites (for mobile applications) (ESA)
SSR Secondary Surveillance Radar
TCAS Traffic Alert and Collision Avoidance System (FAA)

GARTEUR ACTION GROUP FM(AG)03 - FINAL REPORT

1 INTRODUCTION

Discussions in GARTEUR committees and elsewhere over the past few years have highlighted research and development work in many countries aimed at improving Air Traffic Management (ATM) systems; these researches have all involved significantly increased use of computer automation. At the same time, the use of digital avionic systems in all major civil aircraft has rapidly increased; the resulting enhancements to navigation, performance management and precision of flight have been so significant in saving fuel and other costs that such systems have also been fitted in older and smaller aircraft. It has been realised that maximum benefit from these investments in systems can be obtained only when integration into a future total Air Traffic Management (ATM) system has been achieved.

More recently, the strong upward trend in annual air transport movements has caused the need for greater system capacity to become the dominant issue.

A proposal was made in 1984 to form a GARTEUR Action Group to study the "Integration of Flight Management and Air Traffic Management Systems". This proposal was developed by NLR (Netherlands), DLR (Federal Republic of Germany) and RAE (United Kingdom), and was finally approved by the Executive Committee and Council of GARTEUR in mid 1984. This Action Group FM(AG)03 has, since its inception, included members drawn from the above three establishments plus a member from RSRE (United Kingdom). Since early in 1987 an invited member from Eurocontrol has also been included. The first meeting was held in November 1984, since which time a total of 15 working meetings have taken place. Current and past membership of the Group is shown in Appendix 1.

Roughly in parallel with the activities of this Action Group, ATC authorities have also produced concept descriptions of new systems. Examples are the Advanced En-Route Automation (AERA) system concept of the FAA, the Future ATS Concept Description of Eurocontrol, and the ATM section in the fourth report of the ICAO FANS Committee. Because these programmes have been concurrent there has been considerable interchange of ideas and information, and there has been widespread acceptance of the ideas and concepts developed by this Action Group. These other groups have been considering ATM in a more general way including such topics as airspace management, flow management, equipment

specification or communication/navigation/surveillance systems. This Group, however, has concentrated on air-ground integration issues and as a result has developed detailed accounts of the concepts and processes involved in such an integration.

The need for a common and well-organised international approach to future integrated ATM systems has now been recognised by most authorities. The European nations of ICAO, together with other organisations are currently defining the Future European ATS System Concept (FEATS). Within Eurocontrol the definition of a Common Medium Term Plan (CMTP) is just beginning.

A major European collaborative research programme called PHARE (Programme of Harmonised ATM Research in the Eurocontrol organisation) has recently been started. The programme includes studies, experiments and the joint provision of experimental tools, an example of which is the development of an Experimental Flight Management System (EFMS).

The Commission of the European Community (CEC) is in the process of launching an industry programme called EUROMART, the details of the research have yet to be established.

2. AIMS, OBJECTIVES AND WORKPLAN

The Action Group has worked from a knowledge base derived from the current research programmes of its members' organisations. An overview of all of these programmes is given in Section 3, detailed descriptions are given in Appendix 2.

The first aim was to identify the operational and functional objectives which should be incorporated in an integrated ATM system to take full advantage, both from the viewpoints of the aircraft and the ground systems, of the developing flight management systems. Having identified these objectives, the next aim was to explore the feasibility of such a future ATM system. As part of this aim, detailed consideration led first to development of a scenario and then to a conceptual model of essential parts of a future integrated ATM system. It also led to a conceptual model for a future flight management system which was the forerunner of the PHARE EFMS. The final goal, discussed in Section 5, has been to identify those areas where further studies,

research, development or testing are needed, and to indicate the possibilities of international collaboration in these areas.

As part of this work programme several documents, reviewed in Section 4, have been prepared and widely circulated. It is believed that these documents, supported by numerous contributions to international conferences and committees by members of this Action Group, have had a significant influence on long-term ATM thinking in many parts of the world.

In the course of its work the Group received many presentations, working papers and publications. These are listed in Appendix 3.

3 ATM RESEARCH IN GROUP MEMBERS' ORGANISATIONS

3.1 General

The Action Group members are drawn from organisations which between them carry out research into almost every aspect relevant to a future ATM system. Examples of these include airborne precision navigation, flight control, information display, (air and ground) mobile data communication and radar development (SSR modes), as well as ATC automation. Of special significance in the integration of all these components is the recently defined and agreed PHARE programme which, to date, is the largest European research effort in the ATM field.

Detailed and full descriptions of the individual organisations' research programmes are contained in Appendix 2; what follows is a brief summary of these programmes.

3.2 The NLR Programme

NLR operates two research aircraft as well as a moving base research flight simulator. One of the aircraft, a METRO II, will be equipped as the Avionics Research Test bed and will carry programmable avionics equipment. Flight simulator facilities will also be complemented by the required avionics facilities. An ATC research simulator, currently under development, will be available for initial simulations within 2-3 years; it will be interconnected with the METRO II via a data link.

Research relevant for the integrated ATM system includes :

- establishing MLS procedures for straight-in and segmented approaches.
- Consideration of digital flight control and 4D guidance;
- ATM aspects and the integration of avionics and ATC;
- definition of ATM concepts and systems and execution of system studies with emphasis on trajectory prediction, conflict search and enhanced radar data processing;
- design and evaluation of the man-machine interface for controller and pilot.

3.3 The DLR Programme

DLR uses the ATTAS research aircraft for research in many areas including flight control and guidance. It is being equipped with a full set of very flexible avionics and with a removable Airborne Experimental Cockpit. DLR also operates an ATM simulator and a fixed base cockpit; the simulator will be connected with a data link facility and a tracking radar. It is also planned to develop a ground movement research tool.

Research work is dealing with the design and evaluation of :

- a 4D guidance function for the ATTAS aircraft able to satisfy multiple constraints and to communicate with the ground system;
- pilot's and controller's workstation functions and procedures with emphasis on the integration of a data link;
- computer based planning tools for ground movement guidance and TMA control (4D planner and enhancement of COMPAS).

3.4 The UK Programme

The execution of the UK 'Integrated Research Programme into ATM' is shared between RAE (avionics aspects) and RSRE (mainly ATC aspects) and the UK CAA. RSRE uses a real-time ATC simulator; an experimental Mode S station with data link capability is under continuous development, it is planned to link it with

the simulator. RAE operates the BAC 1-11 research aircraft; its avionics equipment is being revised in order to provide the flexibility and the full set of functions necessary for ATM research including the connection with the RSRE facilities.

Relevant research activities of the two establishments comprise :

- development of the Mode S system including the associated surveillance and data link application processes;
- development and evaluation of computer assistance for TMA and en-route control. This includes also the man-machine interfaces for controller and pilot operating in a data link environment (Mode S and satellite) and the implications of Airborne Collision Avoidance System (ACAS);
- development and evaluation of improved control laws and the avionics equipment required for the validation of the air-ground integrated ATM system;
- provision of better meteorological information.

3.5 The EUROCONTROL Programme

EUROCONTROL'S research makes extensive use of the simulation facilities of its Experimental Centre. The real-time simulator is being enhanced to support also the functions required for the evaluation and validation of the future ATM system; an interface with a communication satellite and an improved aircraft representation have been added recently. A powerful fast-time simulation model is available for the evaluation of airspace and ATC organisations.

The research programme covers most areas of present and future ATM systems. In respect to the air-ground integrated ATM system, work concentrates on the following aspects :

- design and evaluation of automated support aids and man-machine interfaces for the future ATM system both with and without data link;
- participation in and coordination of the development of the Mode S system and satellite applications (navigation and communication);

- development and demonstration in a real time simulation environment of a fully automated ATM system (ARC 2000);
- study of the role of controller and pilot related tasks in a concept employing enhanced automation support.

3.6 The Programme of Harmonised ATM Research in the EUROCONTROL Organisation (PHARE)

PHARE coordinates research activities aimed at implementation of the future air-ground integrated ATM system concept. Current members of PHARE are NLR, DLR, RSRE, RAE, CENA and Eurocontrol, together with CAA and BFS. It organises the joint development of certain elements and the validation of the concept by simulation and real-time experiments. PHARE uses the facilities (ground simulators, air/ground data link and research aircraft) of its members. Common development is envisaged of experimental tools such as the EFMS with a data link interface and 4D capability, certain equipment and functions of the ATM ground simulators and of the man-machine interface for controller and pilot.

PHARE will integrate the facilities of the parties to perform the validation of the concept in a larger area by the cooperation of the different ATM ground simulators and research aircraft. Experiments will be performed against a framework of commonly agreed scenarios.

4 PUBLICATIONS

During its working life the Action Group has published an Interim Report and several Working Papers which are described below. The aim of all the Working Papers has been twofold, to give a wide circulation to the problems and concepts on which the Group was engaged and through that to stimulate international discussion on important system issues.

4.1 A Future Air Traffic Management Scenario

From its earliest meetings the Group was of the opinion that a future ATM system would make extensive use of computers and would be based on the planning of precise trajectories rather than tactical interventions. This would be achieved by the exploitation of 4D or time-based navigation principles.

From these basic ideas grew the concepts now associated with this Group and which the scenario set out to describe. The paper reviewed current problems, significant technical developments and guidelines for a future system. Finally, it proposed a system based on air-ground negotiation to define 4D trajectories that were in some sense a global optimum. These trajectories were to be flown unaided by aircraft and monitored by ATC. It has become known as the '4D tubes in space' concept. Unequipped aircraft would still be guided by ATC.

With the agreement of GARTEUR, the paper was presented to the Scenario Group of the ICAO FANS Committee at its meeting at DLR in April 1986. It was subsequently published as GARTEUR TP 024 together with the Interim Report in April 1987. In May 1987, NLR submitted substantially the same paper to the ICAO FANS Committee; their Final Report fully reflects the GARTEUR concepts.

4.2 The Interim Report

The Interim Report, published in April 1987 as GARTEUR TP 025 (RAE Technical Memorandum FS(B)666), described the background to the formation of the Group, its appointed task and the ATM related research programmes in the establishments involved (DLR, NLR, RAE and RSRE). The report also identified the need for the Scenario described in 4.1 and went on to describe the major areas that needed to be researched. The report concluded with a proposal for the next stage of the Group's activity, that of producing a conceptual model of the future ATM system. This document would be much more detailed than the earlier scenario paper. The distribution of the Interim Report was very wide, over 140 copies were printed.

4.3 Conceptual Model of a Future ATM System

The Conceptual Model was completed at the end of 1988 and published as GARTEUR TP 49 (RAE Working Paper FM WP(88)004). The aim of the paper was to:

- (a) Expand the ATM system description given in the ATM Scenario.
- (b) Describe the functions and technological capabilities that would be needed in this system and, where relevant, indicate the present state of the art.

(c) Indicate an evolutionary route to this future system.

It is hoped that this document will provide some of the guidelines for future research within and outside of the GARTEUR organisation. It is planned to give this document a very wide circulation.

4.4 Novel Functional Requirements for a Future FMS

This short paper was also completed in 1988 and published as GARTEUR TP 50, in a common binding with the Conceptual Model.

The ATM Conceptual Model that has been developed changes the relationship between air and ground components to that of active partnership. This new relationship in turn places new demands on the Flight Management System and these are described. Also described is the Experimental Flight Management System concept that has been jointly developed by the participants in the Eurocontrol PHARE programme.

4.5 A System Approach for ATM Beyond the Year 2000

This was a paper written and presented by the Action Group Chairman at the 'ATC 2000' Seminar held at Luxembourg in February 1988. The paper described the GARTEUR organisation and the function of this Group, outlined the Group's ATM conceptual Model and drew attention to some of the major system issues yet to be solved.

The Seminar was well attended and judged to be very successful and therefore was another opportunity to advertise the Group's work.

5 FUTURE RESEARCH

5.1 GARTEUR/PHARE Relationship

The GARTEUR Conceptual Model and the PHARE Programme Description define enabling research that will allow the future ATM system to be designed and constructed. In considering what research topics might be suitable for a successor to this Action Group it might be helpful to compare the characteristics of the GARTEUR and PHARE groups.

This Action Group has excelled at providing a forum in which ideas, arguments and problems are refined and elaborated. In short, it has acted in the best traditions of a 'think tank'. However, the Group is small, meets only a few times a year and can summon only small scale resources. It is therefore not suited to large scale activities such as construction of tools or major experiments.

PHARE on the other hand is planned to be a large scale activity to develop tools and run experiments; it is probably too large to act as a concept generator.

It seems logical that, if it is agreed that there should be a follow on GARTEUR group, to select topics which match these GARTEUR characteristics.

5.2 What needs Study or Research?

The Conceptual Model identifies the following key technologies and topics :

- (i) ATC prediction of aircraft trajectories.
- (ii) ATC surveillance and trajectory monitoring.
- (iii) The controller-computer interface.
- (iv) Airborne optimum profile prediction and negotiation.
- (v) Airborne execution of agreed trajectory.
- (vi) The pilot-computer interface.
- (vii) The definition of trajectories in space.
- (viii) The role of man in a future ATM system.
- (ix) Improved meteorological data.
- (x) Data communication and the data link.
- (xi) Benefits and costs.

(xii) The definition of an evolutionary route to the future.

A definitive task list for PHARE has yet to be agreed, but it will contain topics similar to the above list.

In considering this activity list the Group agreed that :

- The Conceptual Model had been developed to the point where experimental validation of its ideas was necessary.
- The PHARE programme would command larger resources than could easily be devoted to GARTEUR and thus PHARE would form the natural focus of most European ATM research. In passing it was noted that virtually all the Action Group members would also be PHARE contributors and that PHARE would, in the main, be following GARTEUR concepts.
- Some of the above activities were already part of the PHARE EFMS development/exploitation plans e.g aircraft profile prediction, negotiation and execution.
- Some activities now needed detailed development to establish feasibility and achievable performance e.g ATC prediction, surveillance and monitoring.
- Some activities were necessary as part of current EFMS and data link activities, e.g definition of trajectories in space, definition of data link application processes and improved meteorological data.
- Others were more properly the province of National Authorities and international agreement e.g cost benefit analysis and the definition of evolutionary routes to a future system.

The task best suited to the 'think tank' nature of the GARTEUR group is that of the relative roles of man and machine in the extensively automated ATM system of the future.

5.3 Recommendations for Future ATM Research in GARTEUR

The previous section described the process which led to the selection of studying the role of man in the ATM system as the basis for a future GARTEUR task.

Outside GARTEUR there are, and have been, a number of groups seeking to define future automated ATM systems; these include the Eurocontrol ACG, the ICAO FANS Committee, ICAO FEATS and the FAA NASPlan (mainly those features known as AERA 2 and 3). All of these imply a continued role for controllers and pilots but yet none has defined this role adequately. Instead they have concentrated on conceptual, operational and technical aspects.

It is clearly important to recognise that this issue must be tackled whilst there is still time to adopt and change concepts and designs to allow a viable and satisfactory task for the human to do.

It is proposed that a GARTEUR Action Group be established under the auspices of the Responsables for Flight Mechanics. This should be seen to be working in a complementary fashion to the PHARE programme. Basic questions which should be included in the Terms of Reference for such a group are :

1. To identify and compare the relevant characteristics of humans and computers.
2. To identify the nature of viable and satisfactory roles for humans in a highly automated ATM system of the kind defined in the GARTEUR Conceptual Model and other studies.
3. To determine the impact on ATM system design of assigning such tasks to humans.
4. To define the characteristics of the man-machine interfaces, both air and ground, that would be needed to support such controller and pilot roles.

Additional parameters to consider are the practical limitations imposed by airspace structure and sectorising with the consequent need for humans to exchange information.

Because it is considering such a wide range of human factors and system aspects, such a group should be multi-disciplinary. In addition to applied psychologists, there should be operational and technical experts representing air and ground system components.

In conclusion, this Action Group has identified an area of activity appropriate for a future GARTEUR Action Group. Suggestions have been made for the terms of reference of such a group and its constitution. These suggestions are intended to provoke discussion. Further detailed considerations are necessary before the new Action Group can be formally established. These should refine the Group's terms of reference and discuss its relationship with other international activities, particularly the Eurocontrol PHARE programme.

6 CONCLUSIONS

GARTEUR Action Group FM(AG)03 has completed its work with the publication of this final report. In the course of the 15 meetings held since October 1984, it has considered most of the elements necessary in a future highly automated Air Traffic Management system. It is firmly of the view that such a system will only be successful if it is an integrated system, regarding the complementary air and ground components as partners working to their mutual benefit. Working from this basis, a detailed description of a system founded on conflict free 4D tubes in space has been developed.

The Group has in its lifetime produced several working papers which have received wide international circulation and appreciation, notably the Future Air Traffic Management Scenario and the Conceptual Model of a Future Integrated ATM System.

It can confidently be said that the thinking of the Action Group has had significant influence on other international groups, such as the FANS Committee of ICAO. In particular the ATM scenario as presented in the Interim Report of the Action Group was well received by this Committee, and as such is reflected in the final report of FANS.

The ideas contained in the detailed Conceptual Model, together with the FANS final report and the earlier report of the Eurocontrol ATS System Concept Group have shaped much of the European ATM thinking as evidenced in the work

of the PHARE Group within Eurocontrol and the FEATS (Future European Air Traffic System) group of ICAO.

With the publication of the Conceptual Model, this phase of activity is complete. It is now necessary to validate the concepts by detailed studies, simulations and experiments. It is thought that activities on this scale can be done better by the PHARE collaboration which will almost certainly attract wider support than can be obtained through GARTEUR.

The Action Group has reviewed the key tasks which remain to be done and as a result recommends that a successor GARTEUR Action Group be established to examine the relative roles of man and machine in a future ATM system. Some draft Terms of Reference for such a group have been presented together with suggestions for the type of expertise that should be represented.

In conclusion the Action Group would like to thank all those who have contributed to the often lively debate and the support that this sometimes unconventional group has received from their Responsables.

Appendix 1

Current and Former Members of
GARTEUR Action Group FM(AG)03

Current Members

P England (Chairman)	RAE (Bedford), UK
V Adam) DLR, FRG
K Hurrass)
T H M Hagenberg) NLR, NL
T B Dalm)
Dr A J Hughes	RSRE, UK
B Kirstetter (invited member)	Eurocontrol, B

Former Members

R R Newbery (Chairman for first meeting)	RAE (Bedford), UK
J Thomas	DLR, FRG
Dr H Winter	DLR, FRG
P T Humphrey	RSRE, UK

APPENDIX 2

DETAILED DESCRIPTION OF ATM RELATED RESEARCH IN MEMBERS' ORGANISATIONS

1 INTRODUCTION

This appendix is a compilation of the ATM related research in the parent organisation of each Action Group member. A summary of these statements is presented in section 3 of the main report.

2 THE NLR PROGRAMME

In the Netherlands the National Aerospace Laboratory, NLR, is engaged in ATC and avionics research. NLR operates two research aircraft (a Swearingen Metro II and a Beechcraft Queen Air) as well as a moving base research flight simulator. An ATC research simulator is in a first phase of development.

2.1 Facilities

The Metro will be equipped with an Avionics Research Testbed (ART) in order to carry out investigations on the use of and integration of modern avionics in an operational environment. For these investigations it is necessary to have available a flexible avionics system where both the hardware and software can be adapted to the requirements of the specific environment. The realisation of ART will be carried out in three phases:

- (a) Installation of the programmable EFIS.
- (b) Use of a programmable Flight Management Computer and a Digital Air Data computer and installation of a second EFIS.
- (c) Gradual incorporation of MLS, NAVSTAR/GPS, digital air-ground data-link, 4D navigation and sidestick controller.

The existing flight simulator is also equipped with EFIS. A second moving platform with 6 degrees of freedom and improved dynamics (frequency response

and larger lateral and angular displacements) has become available. The existing cockpits can be placed on the new platform.

For the investigation of new ATM concepts and the integration of Air Traffic Management with relevant avionics systems, NLR started the development of its own ATC research simulator (NARSIM). It is expected that an initial ATC simulation facility will be available in 2 to 3 years. Furthermore, it is planned to employ a digital data link between the Metro and NARSIM.

2.3 The Research Programme

NLR's flight test activities will include research in the areas of :

- Establishing MLS procedures for straight-in and segmented approaches
- Use of Navstar GPS for area navigation and non-precision approach.
- Four-dimensional (4-D) guidance and control
- Conventional and unconventional displays with the EFIS
- Coordination between aircraft and ATC
- Digital flight control
- Flight safety

The flight simulator is used for research related to advanced aircraft control systems, handling qualities, human factors, MLS and ATC. Furthermore, NLR carries out studies, together with the Dutch Civil Aviation Department, for the definition of present and future ATC systems. Emphasis has been laid on aircraft trajectory prediction, planning conflict search, radar data processing and also on future ATC concepts.

3 THE DLR PROGRAMME

In the Federal Republic of Germany the German Aerospace Research Establishment, DLR, is engaged in long term research programmes on integrated air traffic and flight management associated with relevant avionics and aircraft technologies. Particular consideration is given to the role of the human operator in increasingly automated guidance and control systems.

3.1 Facilities

Advanced Technologies Testing Aircraft System (ATTAS)

By fall of 1985 DLR had taken delivery of its new ATTAS VFW 614 research aircraft. ATTAS will be used for fundamental research activities in aircraft technology, flight mechanics and flight control, avionics and operational procedures. This aircraft carries an experimental fly-by-wire system, powerful computers and an extensive fit of various sensors which are all accessible to the users via standard interfaces. A comprehensive ground rig offers all hardware and software components needed to test and flight-qualify experimental equipment.

Airborne Experimental Cockpit (AEC)

ATTAS will carry a removable single-seat experimental cockpit in the rear cabin called the Airborne Experimental Cockpit (AEC). The AEC is designed to interface with the fly-by-wire flight control system and the sensor system of the ATTAS aircraft. A four-screen EFIS consisting of flexibly programmable standard A310 hardware is used to realise advanced information concepts for the aircrew.

Initially the AEC will give the ability to pilot the ATTAS aircraft manually by means of a side-stick controller, or automatically via an experimental autopilot. Implementation, flight certification and qualification for experimental use are expected to be finished during 1989. A subsequent upgrading would include an experimental FMS in conjunction with refined displays and intelligent speech understanding.

Hybrid Navigation System

ATTAS will be equipped with a precision navigation system. This system is an integrated navigation system based on a LTN90 inertial navigation system which is aided by up to five DME measurements. Such a system is already working in the DLR DO 228 aircraft. The navigation accuracy is in the order of 30 to 50 meters.

Air Traffic Management and Operations Simulator (ATMOS)

ATMOS is a fully operational simulation complex intended to investigate in real time complex present and future ATM scenarios. The general set-up is centred around a comprehensive and versatile ATC simulation which provides for a realistic representation of air traffic operations at two controller workstations. Optionally the simulation may include a fixed-base cockpit and the ATTAS aircraft in flight to realise a closed-loop ATM scenario with real controllers and aircrew. ATMOS offers standard interfaces to integrate user hardware and software.

ATMOS was used to test the computer based planning system COMPAS (Computer Oriented Metering Planning and Advisory System). In 1987 and 1988 simulations of new Communication, Navigation and Surveillance (CNS) concepts in the framework of the ICAO FANS committee were carried out.

The simulation complex will be upgraded to a more powerful distributed computer system using standard hardware components like workstation coupled via a local area network. This measure leads to a better overall performance (e.g 4D and data link-capability of the synthetic aircraft) and to a considerable increase of flexibility of the simulator.

Ground Movement Simulator (GMS)

As an extension to the ATMOS-Simulation facility a Ground Movement Simulator will be developed in cooperation between DLR and MIT (Massachusetts Institute of Technology) in 1989. The GMS will operate in real-time and will interface with the ATMOS facility primarily by an exchange of information and making use of the pseudo-pilot stations.

More specifically, in addition to the simulated movements of aircraft (targets) on the ATMOS radar displays the GMS allows to simulate the aircraft ground movement very realistically and to display the results on separate ground controller displays. The aircraft movement on the airport taxiways and runways will be controlled by pseudo-pilots, who get the instructions from tower or apron Controllers via a simulated VHF communications link.

Experimental Data Link

The integration of the ATTAS onboard systems with ATMOS using a two-way telemetry link is under way.

Tracking Radar DIR (Digital Instrumentation Radar)

The DLR tracking radar will be integrated with ATMOS and can be used to track the ATTAS and to display its position on the controllers' radar screens. This feature enables the simulation of a Mode S surveillance radar.

3.2 The Research Programme

Four Dimensional (4D) Guidance

The 4D guidance algorithms which were already flight tested in the DLR's test aircraft HFB 320 and NASA's TSRV aircraft (a Boeing B737) will be integrated in the ATTAS computer system. These algorithms rely on enhanced wind filtering and include the calculation of optimal descent profiles. Cooperative interfacing with the ATM system and flexible reaction to its planning needs are the prime concern of this 4D guidance approach. Additional work concerns the development of an experimental autopilot. The 4D guidance algorithms will be extended to comply with multiple constraints during en-route and TMA flight phases.

Pilot's Workstation

One major focus of research is the optimisation of aircrew workstation functions, design and procedures. Future work will concentrate on integrated ATM-compatible FMS layout and improved operator/system interfaces. In addition, a comprehensive set of tools for human factors related overall system performance assessment is being continuously expanded and refined.

COMPAS

An extensive experimental programme involving DLR and BFS (German Federal Administration for Air Navigation Services) has been carried out to study

operational and controller related implications of COMPAS. The philosophy of COMPAS provides for an adequate sharing of tasks between computer based overall planning capability and controllers' professional skills to fine-tune system performance.

At this time there is a contract under way between DLR and BFS which aims at the development of an expanded experimental COMPAS system and its installation at Frankfurt. This system will be used especially to get additional experience in an operational environment and life traffic. The so-called COMPAS-OP system is designed for about 10 control positions. It is planned to have the system installed at Frankfurt in March 1989.

Ground Movement Planning

In cooperation with BFS the DLR will develop and simulate an operational concept of a ground movement guidance system. This concept will be realised in a second step as an experimental system for a specific airport. Finally, this system will be tested under realistic conditions with live traffic at that airport.

4D Planner

In connection to the work for the FANS committee an extension of the system concept comprising higher levels of automation onboard, more computer assistance on the ground, and data link communication was investigated. As an addition to COMPAS, a 4D compatible advisory system was developed to be utilized in a future time based traffic environment. It is a tactical system which helps the controller to handle those aircraft which are not equipped with sophisticated 4D FMS systems.

The planned research work concerns further improvements of computer based planning aids as well as the test of such aids in a real traffic environment. Test flights with ATTAS are planned to study the impact of different levels of automation.

The Data Link Man/Machine Interface

Special attention is being devoted to operationally crucial aspects of future air/ground communication. Studies are envisaged to improve man/machine interaction in aircrew and ATC workstations by natural language conversation with Artificial Intelligence (AI) based components in Air Traffic and Flight Management. Intelligent speech understanding will play a major role to enhance speed, reliability and efficiency in air/ground data exchange via Mode S or satellite digital data links.

The activities described all serve the prime aim of improving ATM efficiency by increased automation and ensuring the adequate involvement of the human operator in emerging new technologies and procedures.

4 THE UK PROGRAMME

In the UK the majority of ATM related research comes under the aegis of the "Integrated Research Programme into Air Traffic Management", usually abbreviated to "IRP". The parties in this programme are the UK Civil Aviation Authority, the Royal Signals and Radar Establishment (RSRE) at Malvern and the Royal Aerospace Establishment (RAE) at Bedford.

The CAA's role is that of overall coordination and data link development. CAA also funds the ATC research programme at RSRE. RAE concentrates on the avionics aspects of ATM, the programme being funded by the Department of Trade and Industry, the CAA and to a small extent by the UK Avionics Industry.

4.1 The RSRE Programme

Work at the Royal Signals and Radar Establishment (RSRE) related to civil ATC is funded by the UK Civil Aviation Authority and is concentrated entirely in one division of approximately 30 staff.

4.1.1 Facilities

Computing facilities available are centred on a DEC VAX 780, supplemented by an increasing number of VAX and SUN workstations. The principal use of the

main computer is for real-time ATC simulation, using several controller positions. An experimental Mode S radar station with data link capability is under continuous development. In addition, the Division can call upon wide ranging expertise elsewhere in the Establishment.

4.1.2 The Research Programme

ATC Systems

Research is carried out into the management of air traffic operations and the implementation of computer assistance, aimed at the future requirements of the London ATC Centre. The research relies heavily on the use of system modelling and the ATC simulator to assess new techniques, system components and especially the interface between the controller and the computer aids. Recent work on arrivals management (landing order, stack departure time and speed control advisers) has now been transferred to the CAA's ATC Evaluation Unit for further development. An approach control adviser is now in an advanced stage of research. Work has recently started on providing computer assistance to reduce controller workload and increase capacity in en-route sectors. The longest term project, in collaboration with RAE Bedford, involves developing concepts and simulations of a future ATM system which capitalises on aircraft with 4D FMS, data links and increased automation.

Data Links:

This group investigates the technological and systems aspects of air-ground data links, with emphasis on the data link function provided by the Mode S radar, for use in future air traffic management systems. An experimental Mode S data link network is being constructed in conjunction with RAE Bedford and CAA. Airborne trials using a simple VHF emulation of the Mode S data link started in 1987; the first trials with the full Mode S system took place in mid-1988.

Mode S:

The Division has been active in this area since ADSEL/DABS were first defined. An experimental Mode S radar station has been developed and based at RSRE, now linked with a second similar station situated at Gatwick Airport. The

programme seeks to develop and evaluate all the hardware and software techniques that will be needed for a Mode S based surveillance and data link system.

Surveillance:

Work has gone on for many years to identify factors which degrade ground-based radar performance, particularly SSR, and to develop solutions to these problems. Previous developments include monopulse radar operation, the use of shaped elevation polar diagrams, the use of diffraction fences and the analysis of Mode C height errors. Current interest includes the many factors affecting SSR surveillance accuracy, novel collision avoidance techniques and ground movement monitoring methods.

Radar Data Processing

This activity investigates the options available for radar data processing and tracking with special emphasis on multiple radar networks. Current activity is concentrating on vertical tracking and on Short Term Conflict Alert algorithms with adequately low false alarm rates.

Software Engineering

This involves the assessment and development of tools and techniques to achieve software of high integrity and reliability for ATC data processing. Previously, emphasis has been on 'fault tolerant' software; currently work concentrates on the use of formal methods for 'fault avoidance'.

ACAS

This activity studies the effectiveness of Airborne Collision Avoidance Systems (ACAS) and the operational implications of such systems. Emphasis is on examining the use of TCAS II in UK airspace, and assisting in the development of international standards.

Human Factors

The aim is to provide Human Factors support to all aspects of the work programme. Topics of particular relevance include assessment of Direct Voice Input in ATC, general aspects of Human Computer Interaction and an investigation of the 'controller/machine partnership' in advanced systems.

Knowledge Based Systems

The objective is to investigate and promote the use of such technology in future ATC computer systems. These techniques are being applied in several areas including implementation of 'electronic' flight strips and development of techniques for improved conflict prediction.

4.2 The RAE Programme

4.2.1 Facilities

The ATM work at RAE Bedford is centred on a BAC 1-11 twin jet aircraft equipped as a flying laboratory. The aircraft was fitted with an EFIS based on two 8 inch square colour CRT displays, an Experimental FMS, an automatic speech recogniser for Direct Voice Input studies, a versatile experimental autopilot, general purpose computing and recording systems and a comprehensive range of navigation aids.

During 1987 a major revision of the aircraft facilities was undertaken. Much obsolescent equipment was removed including the EFMS (which was incapable of further development) and the Direct Voice Input equipment which had been used to control it. A digital signal highway was introduced, based for the present on the ARINC 429 signal format; more modern signal busses will be introduced as they become available. It is planned to install a new EFMS when one becomes available; the EFMS being developed within PHARE would be ideal for this function.

Aircraft experiments are supported by ground development rigs and general purpose computers and laboratory facilities including a high quality graphics workstation for generating display formats.

4.2.2 The Research Programme

Development Support

The nature of the aircraft allows the testing, development, and even the demonstration of products or systems from industry to be readily accommodated. Considerable mutual benefit often arises from this activity as examples of current and future products include an Area Navigation system, a GPS receiver and fibre optic sensor/transmission systems.

Significant support is given to CAA activities, examples include the Prodat ATC satellite based data link, radar and radar tracker calibration and MLS evaluation.

Control Law Development

A small group pursues the development of improved control laws that exploit modern computing hardware. Following development and testing on ground computers, the control laws are hosted in the experimental versatile autopilot for flight test.

A recent example is an energy based control law that is expected to provide more precise control and at the same time offer lower operating cost through reduced fuel burn and engine wear.

This group has also been instrumental in developing a digital flight control computer to replace the existing analogue autopilot to provide an improved interface to trajectory computing systems.

Future activities will concentrate on trajectory execution. That is given that a trajectory has been defined in terms of waypoints and constraints, then a commanded trajectory must be generated and the aircraft guided along that trajectory.

The Man Machine Interface

Modern civil flight decks have reduced the pilot workload in routine operation to a point where further reduction would bring no benefit. However, in present day non routine operation and in future ATC environments, where flight paths and constraints will be much more complex, the existing pilot computer interfaces are inadequate.

Past work has shown the potential benefits of using novel input techniques such as DVI and roller ball devices. Future work will examine the cockpit as an information handling centre and seek to produce displays and input devices that allow the pilot and computer to work together in the anticipated ATM scenario. The representation of 3D and 4D trajectories is seen as a key issue to be addressed.

The graphics workstation is seen as a key to rapid prototyping and testing of these display formats. It is intended that the formats will then be tested in flight using an airborne version of the workstation.

Air Traffic Management

Past work has characterised the capabilities of precision 2D and 3D Area Navigation, quantified turn performance of several commercial Area Navigation Systems and demonstrated some 4D navigation algorithms. These include timed cruise and holding pattern phases as well as a 4D descent system based on speed control.

Work on examining the problems in receiving radio navigation aid data led to the development of a novel real time algorithm capable of accepting virtually any kind of navigation sensor data and exploiting it. The algorithm, known as Data Puddle, has been demonstrated as a multi DME solution.

Considerable work has also been done, in conjunction with RSRE and CAA, on assessing the coverage, performance and role of air-ground data links. A minor milestone was the execution of a 4D descent commanded by data link from a ground terminal. The Prodat satellite based air ground data link has also been extensively tested, examining the characteristics of ADS (Automatic

Dependent Surveillance) as well as the practical problems of near polar coverage and aircraft antenna polar diagrams.

Following the aircraft refit, current and future work pursues improved navigation (through further development of the Data Puddle algorithm, as well as exploration of GPS and MLS as navigation aids), the further development and assessment of air-ground data links and the development of multiple constraint 4D algorithms using energy efficient control laws.

The above developments, including those on the man machine interface, are planned to be hosted on the PHARE EFMS when that becomes available. This would allow an ATM demonstrator to be created that would include the developments of CAA and RSRE and would explore the characteristics and problems of advanced strategic time based ATM systems.

5 THE EUROCONTROL PROGRAMME

The EUROCONTROL ATM research activities are fully described in the Studies, Tests and Trials Programme of the EUROCONTROL Agency. An up-to-date version of the following year is issued in December of each year. The programme covers activities in the fields of:

- A. Radar systems design and evaluation.
- B. Operational research and analysis dealing in particular with the evaluation of the capacity and of the operational efficiency of ATC systems, their impact on flight efficiency and the analysis of aircraft flight profiles.
- C. The application of new facilities and technology in communication and the design of a new controller working position.
- D. The design, development and evaluation of the Mode S system in general and Mode S and satellite based data links including Automatic Dependent Surveillance (ADS) and studies in the field of Automated Collision Avoidance Systems.

E. The development and validation of trajectory prediction and conflict detection techniques and their application as TMA and en-route control and planning tools. In addition, navigation performance evaluation and application design is executed in support of this work.

F. System studies related to the future AFS concept dealing mainly with the development of technical and operational requirements, the development and integration of a new generation of FMSs and the definition of the role of man in a highly automated system; work will be supported by an advanced ATM demonstration system under development at the EUROCONTROL Experimental Centre.

5.1 Facilities

The research makes extensive use of the simulation facilities of the EUROCONTROL Experimental Centre; they are presently undergoing an extensive renewal and enhancement programme. The real-time simulator allows the simulation of both a complete, modern ATC-centre organisation or on a smaller scale the functions and facilities of a future system including the interface with communication satellites. The autonomous computing centre facility is used for arithmetic (fast-time) simulation.

5.2 Future ATM Research

The activities A to F listed above cover tasks dealing with improvements of the current system and tasks necessary for the design and evaluation of the future system as defined by the ATS Concept Group. A more detailed description of the latter tasks is given in the following:

Air Traffic Management tools are concerned with the development of the various techniques and procedures used for the control of aircraft and the management of air traffic with the aim to maximise throughput and to minimise fuel consumption. These tasks include the development and validation of suitable aircraft models, of efficient procedures for the accurate control of trajectories (e.g times at constraint points and optimised traffic flows) and of conflict detection and resolution techniques. Such facilities will be evaluated for the various controller tasks (radar and planning) in real-time simulations for en-route and TMA.

Work in the field of Mode S is performed in close cooperation with member states; it is mainly concentrating on:

- Evaluations and trials of the Mode S system as characterised by the standards adopted by ICAO for international application.
- Studies designed to identify problems that could occur during the transition from the present system to the Mode S system.
- Application of the Mode S system and its data link capability.

The detailed definition of a Mode S implementation plan, which is hoped to start at the beginning of 1989, will give more impetus to the tasks related to Mode S and Mode S data link.

Satellites in ATM are expected to play an increasing role in the field of communications, surveillance (ADS) and navigation. At present the Agency's activities in this field relate to collaboration with the ESA Prodat experiment and to investigation of the operational aspects of ADS. Emphasis is being placed on the interface between ADS and SSR surveillance. Interfaces and interoperability with existing or planned facilities such as SSR Mode S data links are important aspects.

In the field of navigation, studies to prepare for the implementation of a Common Geodetic Reference system will be performed; in addition, aspects of accuracy, integrity and redundancy and the implication of satellite navigation on separation standards will be studied.

A number of aspects mentioned in the Future ATS Concept Description require further elaboration and the translation into operational and technical requirements. Main elements include:

- The development of Flight Management Systems able to optimise and control trajectories in space and time (4D) under consideration of the constraints imposed by ATC and to communicate with the ground computers.

- Role of the controller and pilot in a system employing enhanced data processing techniques. As the degree of computer involvement in the planning role of the controller increases and extends later into the executive function, it is important that the resulting system provides effective support for the controller. The aim is to produce initial concepts for evaluation.

Closely linked to this task is the development of a new working position for the controller which can be adapted in an evolutionary way to new requirements.

The development of simulation facilities for the evaluation and validation of the new features and functions listed above is a major task; the new tools will be designed around the simulation facilities of the EUROCONTROL Experimental Centre.

6 PROGRAMME OF HARMONISED ATM RESEARCH IN THE EUROCONTROL ORGANISATION (PHARE)

Air Traffic Management research managers in the Federal Republic of Germany, the Netherlands, France, the UK and Eurocontrol have agreed on a collaborative research programme (PHARE) that will be managed within the Eurocontrol organisation. The participants are drawn from DLR, NLR, RAE, RSRE, Eurocontrol (i.e the GARTEUR groupings) plus BFS (FRG), CAA (UK) and CENA (F). The participants will harmonise their current and planned activities dealing with the design, experimental implementation and validation of an integrated air-ground system approach. The PHARE activities are fully compatible with the views expressed in the Conceptual Model and could thus be considered as the research programme which naturally follows the work of the Action Group.

6.1 Facilities

Facilities used in individual ATM research programmes of participants with potential for PHARE include:

- Experimental/laboratory aircraft operated by DLR, RAE, NLR, SMFA/STNA (DGAC, F) CEV (F);
- Experimental ground facilities of CAA/RAE/RSRE, STNA, DLR.
- ATM simulators of BFS, CAA/ATCEU/RSRE, CENA, DLR, ENAC (DGAC, F), Eurocontrol, NLR.

6.2 Studies and experiments in PHARE

PHARE is mainly concerned with the integration of the various components and subsystems to form the air-ground integrated Air Traffic Management system and with the determination of the performance of such a system. It will make use of work done outside PHARE and will not duplicate such activities.

PHARE studies and experiments will include:

- (1) The development of scenarios as required for the experiments, based on work developed at ACG, FANS, FEATS, GARTEUR.
- (2) The determination of the required 4D navigation performance of aircraft with 2D, 3D, 4D FMS capabilities in the different phases of the flight in various environments and conditions.
- (3) The determination of the required performance (precision, data available, update rate, integrity) of the surveillance system (Mode S and ADS) in the different parts of the airspace.
- (4) The determination of the required data link performance (data rate, access time, interface with the human element, reliability).
- (5) The development and analysis of the ground element with emphasis on the automation support, the interface between pilot and controller and of the procedures governing the system operation.
- (6) The study of the role of man (controller and pilot) in the new system. This includes the design and evaluation of the interfaces and tools necessary to enable the man to perform his task in a more efficient way.
- (7) The determination of the impact of the concept on the performance of other facilities such as ACAS, GTIS (false alarm rate, warning time).

The ideas, facilities and procedures described above will be integrated into an ATM environment.

Initial experiments will be executed in a pure simulation environment; as the system is maturing a limited number of suitably equipped experimental aircraft will be included; and later, in a pre-operational phase, airlines and operational ATS units will have to be associated.

4 In order to achieve the goals mentioned above, a number of tools, facilities and standards are required. Those of common interest include;

- the development of an experimental Flight Management System, improved meteorological models, the components of ATM simulators and tools for the evaluation of experiments.
- common equipment/software to be used are: EFIS
ATM suite
experimental data link.

Appendix 3

List of Presentations, Working Papers and Publications received by the Action Group

1. Considerations on MLS Approach Path Interception Techniques.
Erkelens and Aardoom, NLR TR 83142
2. Initial views on System Performance of Air Ground Data Communication Systems in relation to needs originating from an Operational Traffic Scenario. T B Dalm, T H M Hagenberg, O B M Dietersen
NLR Memorandum VV 85-008.
3. Investigation on MLS Approach Path Interception and Transition Techniques - Part I.
Erkelens et al. NLR TR 85097U, September 1985.
4. An experimental data link for use by ATC. *
G Stamp, RAE
Distributed FMS
N Witt, RAE
(Presentations to the group 6/8/86).
5. The development of ATC methods - A map for the future. *
P Humphries, RSRE. 14/10/86.
6. Building blocks for a conceptual model of future integrated ATM. *
DLR. 24/10/86.
7. Elements for a conceptual model. *
NLR. 31/10/86.
8. Effects of wind errors on 4D profile tracking for the B747.
R F Moll. NLR Memorandum VV 86-034L.
9. Some RAE thoughts on the route to a conceptual ATM model. *
P England, RAE. 18/11/86.
10. Human factors implications. *
David Hopkin Institute of Aviation Medicine, April 1987.
11. Airway intersection capacity. *
NLR. 16/4/87.
12. Benefits of a future ATM Scenario. *
NLR. 16/4/87.
13. Expected traffic growth - extract from the ACG report. *
NLR. 13/4/87.
14. Current and future 4D navigation. *
U Volckers, DLR/P England, RAE. 24/3/87.

15. Artificial Intelligence and IKBS. *
Presented to the Group by R Mackenzie, RSRE. March 1987.
16. Complementary information on Airway Intersection Capacity *
(two papers summarising current problems).
Eurocontrol. August 1987.
17. Non continuous descent profile - (a short note pointing out an *
operating problem on the L-1011).
Eurocontrol. August 1987.
18. Calculation of actual upper winds by reference to aircraft ground
speeds and true air speeds.
R Ehrmanntraut, H Hermanns, Eurocontrol. August 1987.
19. Elements of a Study Programme - a Eurocontrol discussion paper.
August 1987.
20. Description of the simulation for evaluating the benefits of *
future CNS Systems.
Gerling, Hurrass and Klostermann, DLR.
21. Discussion on monitoring aircraft in tubes. *
T Dalm, NLR. 12/8/87.
22. ARC 2000 (Automatic Radar Control 2000).
Eurocontrol paper dated 28/3/84.
23. Extract from FANS WGI Final Report - extract provided by NLR. *
24. Traffic loads at NIK Intersection (single table showing traffic *
density vs flight level).
Eurocontrol.
25. Outline requirements for new functions to be eventually developed *
on a flexible FMS.
Eurocontrol. 27/4/87.
26. Estimate of a minimum 4D tube size achievable with current technology. *
DLR. 19/8/87.
27. Estimating 4D navigation errors. *
P England, RAE. 17/8/87.
28. Description of 4D tubes/4D paths. *
DLR. 26/11/87.
29. 4D tube definition and waypoint density. *
P England, RAE. 27/11/87.
30. The application of Trajectory Prediction Algorithms for planning
purposes in the Netherlands ATC System.
NLR MP 870310.
J N P Beers, T B Dalm, J M ten Have, H Visscher.
31. Optimal Trajectory of a Plane, X Projet.
Ecole Polytechnique, Paris, June 1988.

* Denotes Action Group Working Paper

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference RAE TM FM 41	3. Agency Reference N/A	4. Report Security Classification/Marking UNLIMITED		
5. DRIC Code for Originator 7672000H		6. Originator (Corporate Author) Name and Location Royal Aerospace Establishment, Bedford, UK			
5a. Sponsoring Agency's Code N/A		6a. Sponsoring Agency (Contract Authority) Name and Location N/A			
7. Title INTEGRATION OF FLIGHT MANAGEMENT AND AIR TRAFFIC MANAGEMENT SYSTEMS					
7a. (For Translations) Title in Foreign Language					
7b. (For Conference Papers) Title, Place and Date of Conference					
8. Author 1. Surname, Initials Garteur Action Group FM(AG)03	9a. Author 2	9b. Authors 3, 4		10. Date	Pages 34
11. Contract Number	12. Period	13. Project N/A		14. Other Reference Nos.	
15. Distribution statement (a) Controlled by – (b) Special limitations (if any) – UNLIMITED If it is intended that a copy of this document shall be released overseas refer to RAE Leaflet No.3 to Supplement 6 of MOD Manual 4.					
16. Descriptors (Keywords) (Descriptors marked * are selected from TEST) Integrated Air Traffic Management, Great Britain.					
17. Abstract GARTEUR Action Group FM(AG)03 was set up in late 1984 to consider how airborne Flight Management Systems and the equivalent ground based Air Traffic Management System could work together to form a genuine Integrated ATM System. A particular problem was how best to utilise the airborne precision 4 dimensional navigation capability that was moving from the experimental realm to airline adoption. The resulting concept of a computer based strategic ATM system utilising 4D trajectories with defined tolerances has become known as the GARTEUR 4D Tubes in Space Concept. These concepts were developed through a series of publications and have proved to be very influential in shaping the thinking of groups such as the ICAO FANS Committee and the PHARE European experimental ATM programme. This final report describes the Group's activities and concludes with recommendations for the work of a successor group. Keywords:					

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